New perspectives on the structure of the Antonine Wall

The Antonine Wall

Papers in honour of Professor Lawrence Keppie

edited by

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Cover illustrations
Front: The Distance Stone of the Twentieth Legion from Hutcheson Hill (*RIB* III 3507) found in 1969 lying face down in a shallow pit immediately to the south of the Wall (copyright Hunterian, University of Glasgow). **Back**: Restored half-life-sized statue of the Roman god Mars from the annexe of the fort at Balmuildy (*CSIR* 129) (copyright Hunterian, University of Glasgow).

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Every edition of the Antonine Wall handbook by Anne Robertson, and more recently edited by Lawrence Keppie, starts with this intriguing quote from the biography of Antoninus Pius in the *Historia Augusta* (Robertson 2015: 13). It is worth considering the Latin quote and its direct translation here (*Historia Augusta*, *Antoninus Pius* 5.4):

> '*... per legatos suos plurima bella gessit. nam et Britannos per Lollium Urbicum vicit legatum alio muro caespiticio summotis barbaris ducto ...*'
>
> ('... through his legates, he waged multiple wars. For he defeated the Britons through the legate Lollius Urbicus, building another wall of turf, after driving away the barbarians ...' transl. T. Romankiewicz and F. Guidetti).

How this *murus caespiticius*, or turf (Latin *caespes*) wall, was made has long interested scholars of the Antonine Wall. Some of the very first scientific archaeological excavations undertaken on the Wall – those by the Glasgow Archaeological Society in the 1890s – were designed specifically to assess its materials and construction. These were published comprehensively and with an eye for constructional details in *The Antonine Wall Report* (GAS 1899). Since then, numerous excavations have been undertaken across and along the line of the Wall, recording various observations about its materials and building techniques but varying in detail depending on the nature of their enquiry. Piecing together the data from these various interventions is a difficult task but in 1974 Keppie published an important paper that still represents a milestone in Antonine Wall scholarship (1974). In 'The building of the Antonine Wall: archaeological and epigraphic evidence', Keppie assessed individual Wall stretches and recorded basic data for the stone base (i.e. the stone course under the earthen superstructure) and the ditch width, where they had been exposed. He also collated all information then available on the materials of the Wall's superstructure, whether of turf or clay (Keppie 1974: Table 1, 156-158). Keppie's work, and the observations made by the Glasgow Archaeological Society, underpinned what remains one of the most thorough discussions of the Wall's construction, that provided in William Hanson and Gordon Maxwell's volume of 1983 (1983a: 75-83). New data on the eastern part of the Antonine Wall was then added by Geoff Bailey in his data compilation in 1995 (1995: 596, 598). What all of this work shows is that the Antonine Wall was not simply another turf wall. Turf was certainly, in terms of volume, the most significant material employed – enough to justify the Wall's description as a *murus caespiticius* (Figure 10.1) – but the entire monument comprising all its architectural elements is better considered an earthen structure, with a key component of it also built in stone (Figures 10.2 and 10.3).

This paper, a tribute to Keppie's work on the construction of the Wall, is intended as a follow-up to his 1974 article, and takes a more architectural and geotechnical approach to the structure. In particular, we will focus on one key issue that the designers, builders, and those responsible for the upkeep of the

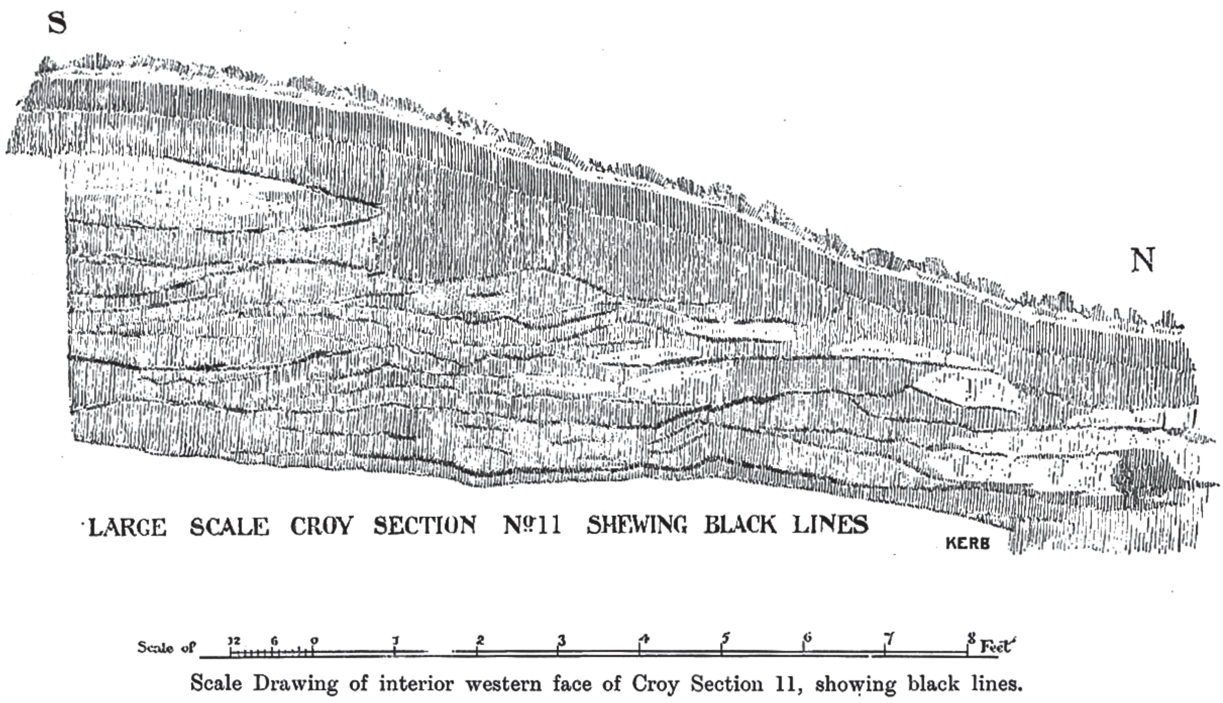

Figure 10.1. Section through Antonine Wall at Croy No. 11, central part, sector 5/6. Drawing shows turf layers continuing from facing (annotated "KERB") through to core and extending beyond southern trench edge; in the north these spread out beyond stone kerb (GAS 1899: 73).

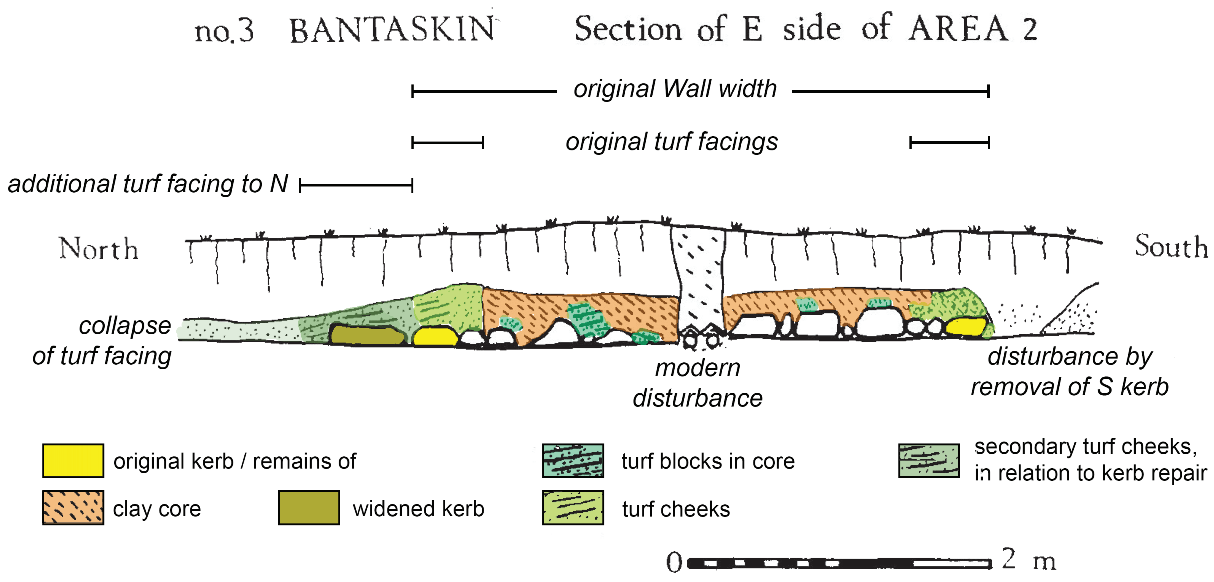

Figure 10.2. Section through Antonine Wall at Bantaskin, eastern part, sector 3. Earthen core of orangey buffy clayey soil, with original wall cheeks of grey lumpy clayish turves; later widened to north (drawn by T. Romankiewicz after Keppie 1976: 71, Fig 7).

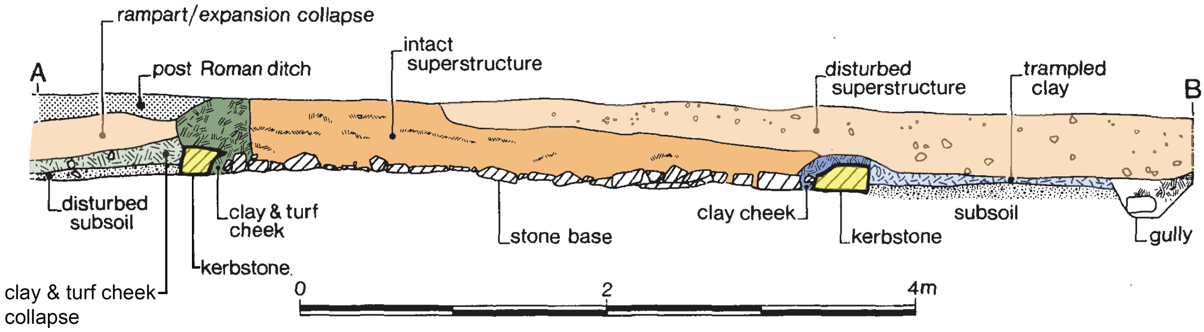

Figure 10.3. Section through Antonine Wall at Inveravon fort, eastern part, sector 1. Earthen core with clay and turf cheek to north and clay cheek to south (drawn by T. Romankiewicz after Hicks in Dunwell and Ralston 1995: Figure 5).

Antonine Wall must have wrestled with: how to manage moisture in an earthen structure the scale of the Antonine Wall in a region as wet as lowland Scotland. Moisture management is a vital aspect of building in earthen materials as water ingress will quickly lead to deterioration and collapse (Jaquin *et al.* 2009; on this point with regard to the Wall, see Hanson and Maxwell 1983a: 80). Even if well managed, earthen structures require regular maintenance to ensure their performance. In what follows, we will argue that the stone base of the Antonine Wall was specifically designed with moisture management in mind; we will then consider how the different materials of the superstructure would have responded to wet conditions, and what the evidence for repairs to the Wall reveal about its performance.

The stone base

The discovery of the 'two parallel lines of squared kerbs [...] with rough bottoming in between' by the Glasgow Archaeological Society near Dullatur (GAS 1899: 42) made it clear that the Antonine Wall had been built on a 'freestone base'. This base is an integral element of the Wall and is more consistent in its construction than much of the superstructure. It comprised dressed kerbs on either edge with a more irregularly-laid rubble fill (Figure 10.4). Built culverts, covered by large slabs, crossed this base at frequent, though not apparently regular, intervals. This general arrangement continues from the Forth to the Clyde, although there are differences in the types and sizes of stones employed: rubble or large cobbles, for example, at Hillfoot cemetery (Figure 10.4); smaller water-worn cobbles and pebbles at Inveravon and Bantaskin; sharply angular material at Bonnyside section No. 3 (Dunwell and Ralston 1995: 526; Keppie 1976: 69; GAS 1899: 111). These differences have been related to material availability but also to the practices of different work-squads (Keppie 1974: 155-156, 161; Keppie in Keppie and Breeze 1981: 238). Changeovers in work parties have also been cited to explain the varying width of the base, ranging between 3.9 m and 5.2 m, with 4.3-4.6 m being the standard (*DES* 1971: 18; Keppie and Walker in Keppie and Breeze 1981: 242; Bailey in Keppie *et al.* 1995: 610). A key point is that changes in the construction of the stone base do not coincide with changes in the superstructure and vice versa. Indeed Keppie proposed that there could have been 'a considerable lull, between laying out of the base and the assembly of the superstructure' (1974: 163).

It is worth revisiting what we know of the composition of the stone base. In terms of materials, the stone for the kerb was sometimes brought from beyond the local area. The Millstone grit used

Figure 10.4. Hillfoot cemetery, New Kilpatrick, western part, sector 9. Stone base of Antonine Wall with angular, dressed kerbstones and rubble core. Arrows mark position of stone drain, i.e. the culverts recorded at intervals (© T. Romankiewicz).

at Inveravon, for instance, or the coarse-grained (amygdaloidal) basalt lava at Seabegs No. 1 do not outcrop immediately adjacent to the Wall but a good kilometre or two away[1] (GAS 1899: 97; Dunwell and Ralston 1995: 526; compare Bailey 1995: 585). In general, however, those materials that were most easily sourced were used: directly available sandstones or derivatives ('whinstone' or 'freestone') (e.g. at Croy Hill No. 11, No. 12a and No. 12; GAS 1899: 72, 79 and 81). Occasional uses of locally available limestone, dolerite, or porphyry[2] are also recorded, for example at St Flannan's Church, Kirkintilloch, or Croy Hill sections No. 10 and No. 12 (GAS 1899: 69, 79; Speller and Leslie in Dunwell *et al.* 2002: 281). The kerbstones were apparently dressed on site, as chippings of the same material were found underneath the Wall core, for example at Inveravon (Dunwell and Ralston 1995: 526; compare Keppie 1976: 65), or for propping and levelling the kerbstones as at Callendar Park, Cadder, or Beancross (Bailey 1995: 585). The core materials of the stone base were either rounded cobbles or only roughly split but otherwise unworked stones.

The stone base was typically built as a single course only (Bailey in Keppie *et al.* 1995: 608), and excavators often comment on the carefully levelled cross-section, as for example at Bar Hill No. 2,

[1] British Geological Survey: http://mapapps.bgs.ac.uk/geologyofbritain/home.html; accessed 09/09/2019
[2] British Geological Survey: http://mapapps.bgs.ac.uk/geologyofbritain/home.html; accessed 09/09/2019

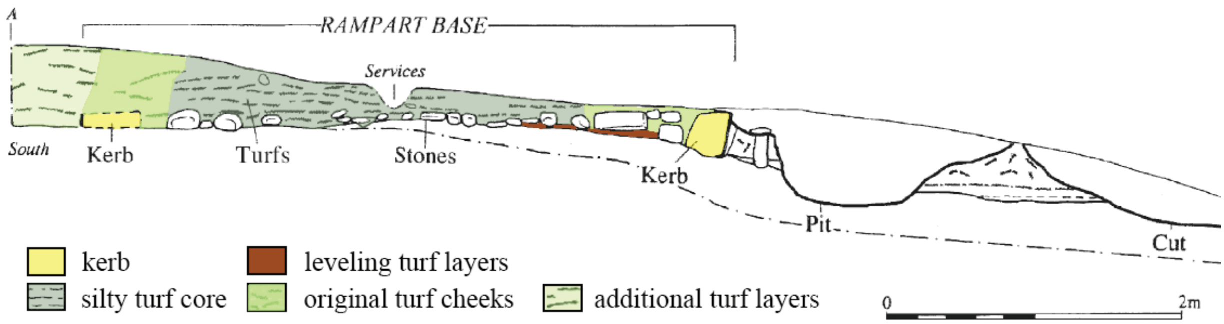

Figure 10.5. Section through Antonine Wall at St Flannan's Church, Kirkintilloch, central part, sector 7. Ground was levelled by turf layers underneath northern stone base (brown), demarcated by kerbs (yellow). Superstructure seems to consist of compressed turf core with narrow vegetation lines (grey), flanked by two less well-layered and potentially slumping faces to north and south (green). Additional stack of layered turf was placed in front of south kerb (light green) and has been interpreted as buttress to retain failing south turf cheek (drawn by T. Romankiewicz after Speller and Leslie in Dunwell *et al.* 2002: 283, Figure 17 (east facing section, Trench C)).

although individual stones also protrude upwards (GAS 1899: 43, 72; compare 92). At Balmuildy Road, however, such 'inequalities of the core [were] levelled off with a layer of yellow clay' (Keppie 1976: 66). Where two stone courses survive, Keppie proposes they relate to vertical steps built to negotiate slopes and to mitigate against slippage of the superstructure, as at St Flannan's Church, Kirkintilloch (Speller and Leslie in Dunwell *et al.* 2002: 281). At Carleith, the slope may explain the atypically wide stone base of up to 5.2 m (compare Keppie 1974: 155). The base in Douglas Park, Bearsden, was also widened to 4.5 m from the average of 4.3 m but the topographical location is complicated by modern landscaping (Keppie 1976: 74). Wider wall bases spread loads across a larger area and mitigate slippage or subsidence. Terracing underneath the stone base is known from Garnhall Farm, Area 1 (Keppie in Keppie and Breeze 1981: 238). Alternatively, like at St Flannan's, sloping ground was raised up by retaining the natural vegetation-covered ground surface in places, and adding further turf layers to create a level platform (Figure 10.5, in brown) (Speller and Leslie in Dunwell *et al.* 2002: 281). A 'grey sticky silt' was used at Balmuildy Road to replace the original ground surface (Henderson in Keppie 1976: 66), though this might itself represent the remains of a levelling turf course. Likewise, kerbstones protruding about 0.3 m above the level of the stone base core at Croy Hill section No. 8 would have helped to retain the superstructure material and bracketed the turf wall against bulging at its foot (GAS 1899: 65). Individually protruding stones would have had a comparable effect, increasing the friction and stability between superstructure and stone base. In this context the levelling clay at Balmuildy mentioned above may have been counterproductive. In these ways, the Wall construction could follow the undulating ground and soundly negotiate slopes along both its longitudinal and perpendicular axes. The picture that emerges is that considerable efforts were made to provide level cross-sections to counteract potential slippage or subsidence of the superstructure (Hanson and Maxwell 1983a: 81).

Base or foundation?

The stone base in itself was a massive logistical undertaking – but what was its primary function? The discovery of the stone base of the Antonine Wall in the nineteenth century coincided with the recognition of the turf component of Hadrian's Wall at Appletree, near Birdoswald (GAS 1899: 170-171; Breeze 2019a: 40, 45). In contrast to the Antonine Wall, the original turf and clay section of Hadrian's Wall, stretching for 45 km west of the River Irthing to Bowness-on-Solway was only sporadically built upon a stone base (Simpson and Richmond 1935; Crow 2004: 120; Breeze 2019b: 12). Roughly built of cobbles, gravel, and some 'large freestones', which seemingly formed only a rough kerb, these were not laid as neatly as the stone base of the Antonine Wall (GAS 1899: 171). Cobbles or even timber strapping have also been found beneath fort ramparts in Britain, though these are again usually quite ephemeral and sometimes run under only part of the structure (Jones 1975: 74; Hanson and Maxwell 1983a: 80). Why the stone base was included in the plan of the Antonine Wall when it had not been used systematically for the turf sections of Hadrian's Wall remains a point of discussion (Breeze and Dobson 1972: 199; Breeze 1982; Hanson and Maxwell 1983a: 109-111; Breeze 2006: 71-74; Graafstal 2012; Breeze 2009; Breeze 2019a: 45, 48 and 64; compare Gillam 1975). Had the planners of the Wall learnt from Hadrian's Wall? Or had they learnt from other Roman fortifications in Britain, such as Slack, Templeborough, Old Church (Brampton), Throp, and Castleshaw II (see discussion in Richmond 1936: 191-192)? What benefits did the stone base provide for a turf wall? Structural and geotechnical analyses can provide some insights here.

From a structural point of view, the levelling function of stone bases is no doubt beneficial to reduce or eliminate lateral or overturning forces which cause sliding or slumping and possible cracking in the superstructure; what applies to modern brick walls with cement mortar applies even more so to a less rigid turf wall (British Standards Institute 2005). Even if the yielding properties of a turf superstructure result in uneven compression and hence amplify unevenness during its lifetime, maintaining a high construction quality in the early stages could have enabled improved performance in maturity. Levelling of the kerbstones for the Antonine Wall, however, would not have produced any additional retaining function: it is unlikely that kerbstones more or less level with the core could have braced the turf superstructure and thus resisted its thrusting forces at its base, especially since only a single, low and unbonded course was built. Only a vertically protruding kerb as evident at Croy Hill section No. 8, discussed above, could have achieved such retaining properties, but this construction detail was not applied systematically. The stone base does occasionally project beyond the edge of the superstructure, as on Croy Hill (GAS 1899: 78; Hanson and Maxwell 1983a: 108-110, pl. 6.1) or possibly at Tentfield (Robertson 1964: Fig. 5; see discussion below), but in general the kerbs of the stone base were flush with the faces of the superstructure and since the stone base only comprises one course of stones, it is unlikely to have been designed to function as a structural foundation, that is to spread a load over an area larger than its superstructure. The term 'stone base' should therefore continue to be used preferably to 'stone foundation'.

Drainage

While the stone base probably facilitated construction across topographically awkward areas, the fact that it was used for the entire length of the Wall indicates that it had a different primary function.

In 1983, Hanson and Maxwell argued that a principal purpose of it was to allow for the provision of built culverts, which would have prevented the build-up of water in zones where the Wall blocked natural drainage (Hanson and Maxwell 1983a: 80). This is a key observation. Pooling water seeping into the superstructure would certainly have weakened the turf material and promoted slumping. The culverts would have helped direct large quantities of water through and under the Wall's vulnerable superstructure. Indeed it is striking that when the turf and clay section of Hadrian's Wall was rebuilt in stone, culverts were inserted at regular intervals, a feature not found on the original stone section of the same structure (Breeze 2019b: 26).

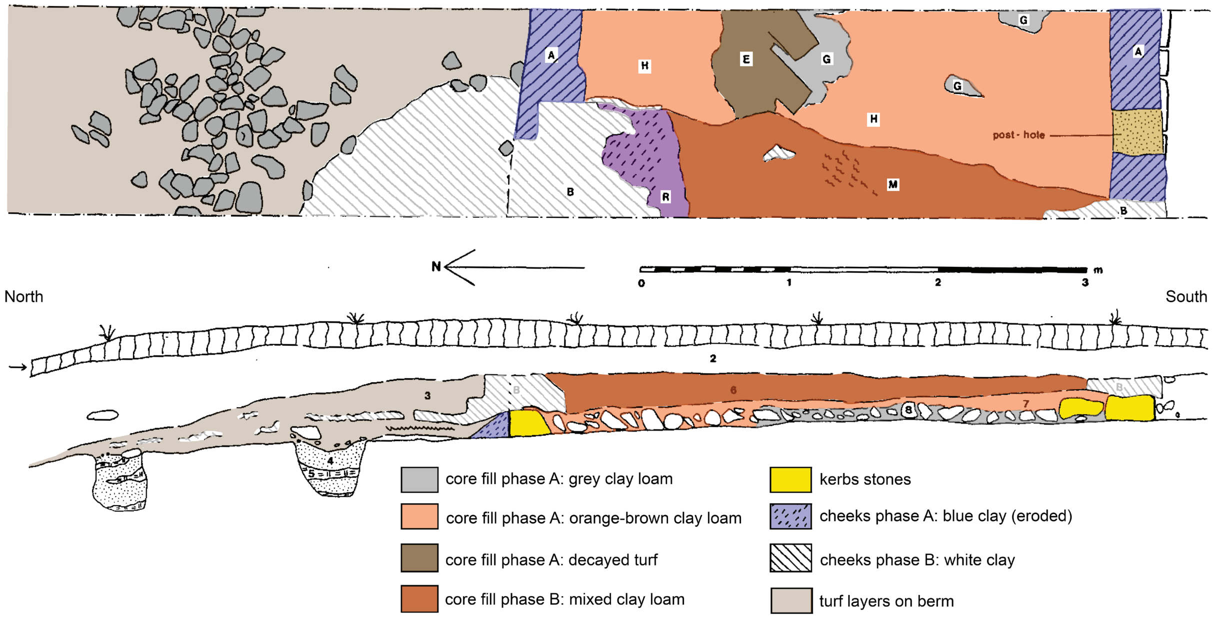

Figure 10.6. Plan and section through Antonine Wall at Callendar Park, eastern part, sector 2. Bailey's excavation in 1989 revealed a change in construction between an earlier (to east) and later phase (to west). White areas ('B') within the Wall were recorded as V-shaped spreads of white clay, possibly representing how these later cheeks were keyed into bulk material of later core ('R' and 'M'). This subsequently collapsed and spread to the north beyond Wall (drawn by T. Romankiewicz after Bailey 1995: Figure 3).

This argument can be taken further, however, for it was not simply the culverts that would have facilitated drainage. The drystone (i.e. unbonded) kerb and rubble base of the Antonine Wall would also have allowed ground water to drain through it without seeping into the superstructure above. This was a point that the 1890s excavators made, but one which has not been echoed since (GAS 1899: 127). This would have been particularly effective when the stone base was built on top of the ground surface and not cut into it, which appears to have been the normal situation. Even when the base was laid on surfaces stripped of their turf, the areas either side of it also seem to have been stripped, as at St Mary's (Bo'ness), Croy Hill section no. 11, Tentfield and Wilderness West (Bailey in Keppie *et al.* 1995: 608; Robertson 1969: 39; 1964: 193; Hanson and Maxwell 1983b: 229). Small details, as recorded in Bailey's section at Callendar Park (Figure 10.6), suggest that the kerbs in effect protruded above ground (1995: 583, 585 and 587; compare Figure 10.3 for Inveravon, Dunwell and Ralston 1995: 531). Bailey's section drawing shows a triangle of clay material (Figure 10.6, in blue), which had eroded from the earlier clay cheeks, demonstrating that the stone face had been exposed in the original construction. Even if the stone base was cut into the hillside along its rear side, the fact that it was unbonded would still have increased drainage, assuming the front kerb stood proud of the ground surface.

Rising damp and freezing

The slight elevation that the stone base gave the superstructure of the Wall would have had two additional benefits: it would have militated against erosion arising from splashing as rain struck the surrounding ground and it would have prevented moisture ingress through capillary rise. Modern earth buildings address this issue by providing earthen walls with low-permeability stem walls (or stem walls with a damp-proof course), roughly 200 mm high (Easton 2007). Although this may seem a superior solution compared to a permeable base, an impermeable base can be detrimental if water is allowed to gather within the material above it. This is a crucial point for the Antonine Wall, which is rarely discussed. While the stone base certainly facilitated drainage of water from one side of the Wall to the other, it also increased drainage of water from inside the superstructure itself (see GAS 1899: 127). Indeed, this is the approach taken for large modern earthen structures, for example dams; a high-permeability base layer of gravel or sand is used to control water levels within the structure (Fell *et al.* 2005).

Dampness within a turf wall can lead to gradual degradation and eventual failure, as well as the more rapid slumping mechanisms discussed above. If not controlled, dampness in turf walls accelerates the rate of decomposition of the turves' organic matter by fungi and bacteria, causing the turf blocks to shrink, crack and lose structural integrity (Sigurðardóttir 2008: 13; Johansson *et al.* 2012). Moreover, water within turf walls can lead to freeze-thaw cracking and crumbling, resulting in structural instability and, ultimately, damage that requires repair (Vésteinsson 2010: 21; Sigurðardóttir 2008: 13). The reason for this is not simply the 9% volumetric expansion of pore water upon freezing. As air temperatures dip below freezing, the freezing front moves from the outer edges of a turf wall into its core and ice lenses form parallel to this front. If a turf wall is part of an open system, connected to the soils below where water is available to rise into the structure, and/or if unprotected so that water can enter the wall core from above, the temperature and cryosuction gradients (a water pressure gradient established between water and non-wetting ice bodies in the soil pore spaces) will draw available water towards the freezing areas. This will cause ice crystals to grow larger and the ice lenses to expand (Rempel and Rempel 2019). Upon thawing, these ice lenses leave cracks parallel to the wall surface, which cause fragments of soil to spall off, eroding the outer surface of the wall (Taber 1929; 1930; Walder and Hallet 1986; Hallet 2006). Factors that exacerbate ice lens formation, frost heave and frost weathering in soils include its particle-size, especially the quantity of small soil particles and voids like those found in clays, and the abundance of water, including water deeper down in an open soil system. Soils containing abundant organic matter, such as turves, also cool more slowly than more mineral-dominated soils. A slower rate of cooling, in which temperatures remain close to freezing for longer rather than rapidly dipping far below, exaggerates ice and frost damage, as do multiple cycles of freezing and thawing (Taber 1929; 1930; Rempel and Rempel 2019). The physical geography of the Antonine Wall in the cool Atlantic climate of southern Scotland, the use of clay and clayey turves, the abundant precipitation and the frequent freeze-thaw cycles typical of winters in the region, are all aspects conducive to ice lens formation, disturbance by frost heave, and hence the weathering and erosion of the Wall. The stone base, with its extremely coarse 'particle' size (i.e. its stones) and larger voids, would have acted as a moisture barrier, keeping the wall turves drier and protecting them from the damaging effects of both organic decay and frost.

Ethnographic evidence supports these modern geotechnical conclusions, but even in northern regions with long turf-building traditions, the practice of placing stone foundations or bases under turf walls developed only over time, as the understanding of why turf deteriorates improved. In the ninth and tenth centuries, turf was the dominant structural material for both buildings and boundary walls in Iceland and Norse Greenland, for example. Stones were commonly (though not always) used as a base, but for the outer turf facings of house walls only. This base did not span the entire width of the walls (Ágústsson 1987; Ólafsson and Ágústsson 2004; Stefánsson 2013). Likewise, the numerous sections that have been excavated through Viking-Age and Medieval turf-built farm boundary walls and earthworks in Iceland have occasionally revealed stones within the wall cores, but no use of stone foundations or stone bases (e.g. Einarsson 1995: 87; Lucas 2009: 155-159; Einarsson and Aldred 2011; Milek 2011). Although many Old Norse written sources refer to turf wall-building in Iceland, none mention the use of stone bases. The earliest known written reference advocating the construction of stone bases for turf houses in Iceland is a paper from 1790 by Guðlaugur Sveisson, which suggested that stones should be used under the inner and outer turf faces of walls, and that the inner soil and turf core should be underlain by sand, gravel and/or stones. Regardless of this recommendation, walls continued to be constructed without full-width stone bases until the mid-twentieth century, although it became increasingly common to use multiple courses of stones, up to a metre high, under the inner and outer turf facings of house walls (Milek 2012; Edwald and Milek 2013; Stefánsson 2019). In 1904, Jón Þórlaksson published a newspaper article (cited in Stefánsson 2019: 48-50) arguing that the most important improvement needed for Icelandic turf houses were solid stone bases bound by mortar at the top. Today, turf-building practitioners and instructors, including employees of the Icelandic museums responsible for restoring or rebuilding old turf walls, commonly lay one or two courses of stones under the entire width of turf walls – even if the core of the walls being repaired did not originally have full-width stone foundations (Sigurðardóttir 2008; Hjörleifur Stefánsson, pers. comm.). Therefore, although full-width stone bases are not a traditional feature of Icelandic turf wall-building, they are now considered best practice. Based on the structural evidence discussed above, we can safely assume that the builders of the Antonine Wall considered the stone base to be best practice as well.

In summary, the stone base of the Antonine Wall seems to have been used to provide a level surface, to mitigate slippage, to provide a solid framework through which culverts could be threaded and to reduce moisture in the superstructure, which in turn slowed the rate of organic decay and limited frost damage and erosion. What it did not provide was the structural advantage of a foundation, since it could not distribute the load of the superstructure over a wider area.

Variations in the superstructure and their impact

The discussion above has focused on the stone base and its role in protecting the superstructure from the detrimental effects of excessive dampness. As noted already, however, the superstructure itself was not constructed in the same way throughout its length. East of Watling Lodge, in particular, various excavations have suggested the Wall was not made of layered turves but of an earthen core faced by turf or even clay cheeks (see Macdonald 1921: 22; Keppie 1974: 71, 78). We should not assume that these construction techniques were limited to this sector: there is, in fact, evidence for turf cheeks in the central and western sectors (a topic that will be explored in a future publication). Further investigation along the line of the Wall is needed to confirm the extent of this variation but from what is already known, it is evident that the builders of the Wall were provided with considerable flexibility in how they achieved the desired end results (compare Hanson and Maxwell 1983a: 111) – that is, a superstructure that was probably intended to have a particular profile along its whole length; indeed they had to have had this flexibility since the Wall traversed such a range of landscapes, with different soils and vegetation coverage (Robertson 2015: 17; Tipping and Tisdall 2005; compare Macdonald 1925; 1934: 86-87). This variation in building materials and techniques was not unique to the Antonine Wall: the builders of the original western section of Hadrian's Wall were also forced to adapt their approach, in most cases using turf, in other instances compacted or 'beaten' clay (Simpson and Richmond 1935: 14); again, this would appear to be a response to the varied terrain through which the structure was built.

Regardless of the extent of these different modes of construction, and the actual structure of the Wall along its length, what can we say about their impact on its performance, particularly with regard to issues of drainage and erosion? While the variously constructed sections of the superstructure might have looked the same, would they have behaved differently long-term? Here we need to consider the building material properties of turf and clay.

i. Turf

In cool and wet northern regions, turves can be acquired from the tough, dense, tangled root mat that binds the topsoil together (referred to as the A-horizon). This renders it relatively easy to dig blocks or strips out of the ground with a spade and to custom-shape them with a blade (Sigurðardóttir 2008; Milek 2012; Huisman and Milek 2017). The high percentage of organic matter and air (voids) in turf also makes it light and relatively easy to handle – an important factor when building large structures (Steinberg 2004). Clay might have been easier to move over longer distances once loaded in baskets, but loading and unloading this heavy material would have put strain on the workforce (Shirley 2000: 97-98). Once stacked and buried within a wall, turf and clay also undergo different post-constructional changes. Turf is subject to desiccation, decomposition by fungi and bacteria, shrinkage of its roots and the upper 'litter' horizon of plant fragments, the loss of organic carbon and the compression of its abundant void spaces (Macphail *et al.* 2003; Macphail and Goldberg 2018: 99-125). To minimize post-constructional shrinkage, which can be substantial, it is common practice in northern regions to dry turves for buildings for at least two weeks (Sigurðardóttir 2008) and to ensure these are well trodden during construction. In other regions, however, turf is used 'fresh', i.e. within a day of being cut; indeed Vegetius suggests using turf for temporary camps, which would have been erected within a day (*De re militari* III.8; Welsch 1969: 14). Shrinkage through drying may have been less of an issue for temporary structures, or for such open systems as turf ramparts, compared to thinner, roofed-over house walls, but their turves will also shrink over time due to organic decomposition and further compression. This creates spaces within and between turf blocks that render them prone to cracking, crumbling, slippage and, ultimately, sagging, erosion and structural collapse (Vésteinsson 2010: 19; Milek 2012; Edwald and Milek 2013: 13-19). To promote the longevity of a turf structure, therefore, it is necessary routinely to monitor the coherence and integrity of the turf, and to replace rotten, crumbling or slipping turves frequently and quickly. In Iceland, where turf was the most common building material from the ninth to the twentieth centuries, and where it is still sometimes used for animal buildings today, turf in walls needs to be replaced at least every ten to 20 years, and turf structures need to be completely rebuilt every 50 to 60 years (Milek 2012; Vésteinsson 2010: 21 and footnote 1 for numerous historical references).

The geotechnical behaviour of turf is also relevant here. Turf is soil bonded by grass rhizomes and humic substances containing the voids described above. Placed near the bottom of a wall, these will become moderately compressed, whereas turves nearer the top may retain more voids. It is therefore reasonable to assume, but as yet unproven, that those turves near the bottom of the wall will be less permeable to water than those nearer the top, because the voids in the soil, especially channels created by roots and soil fauna, will be smaller. As it would be easier for water to pass through the upper material, it is also reasonable to suggest that water would collect in the lower turves, with higher water contents nearer the core (as water can evaporate from the outer surfaces). This compression model is supported by the record at Croy section No. 2, where the horizontal dark vegetation lines (the A-horizon, see above) 'have a tendency to converge towards the centre, and curve upwards from the centre to the outside of the vallum' (GAS 1899: 50). The compression in the centre has been so dramatic that they 'unite in a dense mass' (GAS 1899: 50-51). At Bonnyside No. 3, a 'depression of the layers in the centre, from which they curve upwards towards the external face of the vallum' was noted, which was most pronounced on the south face (GAS 1899: 111-112). Higher water contents would reduce the load-bearing strength of the material, helping to explain why the stone base was so key. As noted above, the 1890s excavators already observed this: 'this base course of stone made the footing of the wall firmer, drier, less liable to subsidence and bulges ... [and] served to allow the water in the vallum to pass down through it ..., but it must also have prevented the vallum from gathering damp from below by direct contact with the soil.' (GAS 1899: 127).

ii. Clay

Clay, compared to turf, comprises nanoscopic particles whose structure is dominated by material electrostatic and hydrodynamic properties (Hillel 1998: 75-97). This means for natural clayey soils, which comprise aggregations of clay and other (larger) particles, it is important how these structures are arranged because this affects how easily water can move through them. One way to reduce the hydraulic conductivity of clayey soils is to break down these structures, significantly narrowing what pore spaces remain, through the process of puddling. Bailey proposes that the clay used in the cheeks he identified during the Callendar Park excavations was extracted locally, thrown between wooden shuttering and 'puddled *in situ* by soldiers tramping up and down on the encased material' (Bailey 1995: 586). However, puddled clay is mixed and kneaded with water into a plastic state and needs to be kept wet; once it dries out it is highly susceptible to cracking (Hillel 1998: 366). Puddled clay, therefore, could not have been used to build load-bearing elements. It is usually used to line basins or canals, as it was in nineteenth-century Britain, and to form the cores of earthen embankments (Brandt *et al.* 2016: 165). If the clay used in the Antonine Wall was puddled, then it would have to have been applied in a plastic state, patted onto the exterior of the core rather than built up in the form of cheeks. In this context, Bidwell and Watson have made an important observation on Hadrian's Wall (1996: 19), where the clay material found in the core of certain sections of the stone wall is often described as 'puddled' (e.g. Daniels 1978: 16). This is a terminological error. In fact, as they note, the clay found at Denton was not puddled; instead it retained some brown silt material suggesting that it had not been processed following extraction and had simply been compacted by treading (Bidwell and Watson 1996: 19). In the turf and clay section of Hadrian's Wall, Simpson and Richmond also only ever refer to 'beaten clay', and not 'puddled' clay (1935: 14). In fact the clay used in the cheeks at Callendar Park on the Antonine Wall was probably also simply compressed and not actually puddled (see Bailey 1995: 586). This clay could have been mixed with fibres to create a form of cob, packed in place between temporary shuttering – a technique referred to as shuttered cob or *bauge coffrée* in French scholarship (Cammas 2018: 170-171). Alternatively, a moist (though not wet) clay-rich subsoil could have been packed between shuttering in the same way as the brickearth walls of Roman London (Perring and Roskams 1991: 67, 78-80). However, too little survives at Callendar Park to be sure about the exact materials and construction technique used. It is also not clear how a construction of a mixed earthen core, presumably compacted, with clay cheeks on either side would have fared structurally (see Figure 10.6). This is a question that will require further analytical testing to answer fully.

If the clay used on the exterior of the Antonine Wall was genuinely puddled, and not simply compacted to form cheeks, as seems more likely, then it might actually have had a detrimental effect on the superstructure itself. Building upon the assumptions that turf permeability reduces with compression and puddled clay materials have even lower permeability values than the turves, then applying puddled cheeks to the superstructure of the Antonine Wall would have made the overall construction more resilient to water ingress from outside. Their low permeability would have protected a more absorbent turf core from rainfall and splashing water. However, such a clay layer with low permeability would also have prevented any water already inside the wall core from escaping. Water trapped inside the core or which entered via rising damp or from above would potentially have built up within the superstructure and caused damage to the cheeks and the turves in the core, such as the spalling off discussed above for frost damage. Compressed clay cheeks, in contrast, would have allowed some permeability for evaporation while also providing limited protection from external water; it would not have sealed the core of the superstructure, but this would not have been desirable.

Despite the ability of clay cheeks to protect a more absorbent core from rainwater, their surface would nonetheless gradually deteriorate under direct rainfall, which would remove loose particles from the wall face. Such fine erosion of clay cheek surfaces has been recorded at the southern rampart of the small fort at Inveravon in the form of a very fine clay deposit (Dunwell and Ralston 1995: 547). Similar evidence can be seen in the material eroded against the northern kerb at Callendar Park (Figure 10.6, blue triangle). Exposing the cheeks to wetting and drying cycles would additionally degrade the material due to differential shrinkage and swelling (particularly if combined with freezing and thawing cycles, as previously discussed). Exposed clay cheeks would not therefore have had a particularly long service life and on any structure designed with faces of this sort, a regular programme of repair and replacement would have to have been planned. Those sections of the superstructure of the Wall built in solid turf or out of turf cheeks and a turf core had a clear advantage here. A living grass cover on the top of the superstructure would have provided some protection from rainwater ingress. Likewise, turves at the outer surfaces of the cheeks could have continued to grow, providing further protection. Re-growth is not guaranteed – in Iceland, where turves are still used for construction, it is often patchy, especially on the sides exposed to the prevailing wind – but any additional grass coverage would have provided some defence against erosion. The only way that clay cheeks could have been made more durable against moisture impact would have been by providing them with a covering of some sort. Clay-based building materials, when – and this is a key point – protected from rain and rising damp by stone plinths and overhanging roofs, dry very hard and need little maintenance for decades (Minke 2006). Even Vitruvius, who rarely mentions earthen materials, notes that mudbrick walls perform well if properly roofed (*De architectura* II.8.16). Suitably protected clay cheeks, therefore, could have lasted well beyond the ten to 20 years noted above as typical for turf structures. It is difficult to see how these clay cheeks could have been protected except with some form of built cover on top. However, we know little about arrangements along the top of the Wall and indeed some argue there was no walkway along it (Hanson and Maxwell 1983a: 83; Breeze 2006; compare Bailey 1995; Robertson 2015: 18). Whether the Wall head was accessible or had a construction on top would also have had structural implications, and the stability of such a reconstruction remains to be tested.

In summary, the turf sections of the Antonine Wall would have been vulnerable to dampness, but since slightly raised on the stone base, which provided drainage and militated against rising damp and frost damage, these could have had a lifespan of 50 to 60 years, as noted above, if regularly maintained.

Cheeks, in either clay-rich turves or clay, might have had some benefits in terms of water management, potentially protecting the core from direct and indirect rainfall. However, they are also likely to have slowed moisture loss from the core, especially when made in compacted clay. Clay cheeks, in particular, would have been vulnerable to erosion themselves and would have needed regular repair unless they were in some way covered. So either these cheeks were left open to the elements and had to be regularly repaired, which is perhaps the most plausible option, especially in light of evidence for collapse and repair (discussed below), or they were protected in some way and so would have had a much longer lifespan. It is interesting to note that clay cheeks are not found in other large-scale Roman structures post-dating the Antonine Wall, which may suggest that this construction was not quite the ideal solution.

Maintaining the Wall

The above observations highlight a key aspect of the construction of the Antonine Wall of which we need to be aware: that sections of it would frequently have been taken down and rebuilt, when and where alterations or repairs were necessary. As building materials, turf, clay and other earthen mixtures are extremely vulnerable to erosion and decay, but at the same time extremely versatile because they are easily shaped and, unlike stone or wood constructions, do not require individual components to be tied together (Minke 2006; Sigurðardóttir 2008; Friesem *et al.* 2017). This means that repairs or alterations can be done more frequently and in a piecemeal fashion. It would take little time or effort to remove sections in need of repair, to rebuild or add sections, to create or block passageways through the Wall, or to add an additional facing to support a slipping or eroding front (for discussions of turf constructions, see Vésteinsson 2010: 31; Edwald and Milek 2013: 13-19; for discussions of mud and clay constructions, see Minke 2006). At various points along its length, there is evidence that the faces of the Antonine Wall did require continual attention and, in some cases, substantial repairs (see Macdonald 1911: 398; compare Keppie 1976: 75-76 in relation to the widening of the stone base).

In the turf sections of the Wall, individual turves bulging beyond the line of the kerb of the stone base were noted already by the Glasgow Archaeology Society and attributed to distortion caused by the pressure of earth above and military movements (GAS 1899: 127). A re-assessment of section No. 11 at Croy corroborates this observation, linking the protruding turves to accidental slippage rather than to a deliberately built extension (see Figure 10.1). At St Flannan's Church, the material in front of the southern turf cheek (Figure 10.5, light green), seemingly much better layered than the turf cheek above the kerb, could well represent turf laid against a failing original face. At Tentfield, Robertson inferred repairs or slippage seen in the form of regular turfs stacks recorded in front of the original cheeks (Figure 10.7). She admitted that it was hard to discern whether these were deliberately layered and thus constructed as cheeks or simply slipped from the superstructure above. While the first cheeks had their footpoints bracketed by the kerb, i.e. the kerb would have protruded, Robertson's record drawings suggest that the second cheek was carefully built on top of the kerb stones and against those original turf cheeks, presumably to counteract their sagging outwards at the front and rear of the Wall (Figure 10.7) (see Robertson 1964: 193, Fig. 5).

Some of these repairs necessitated alterations to the stone base, as noted in section No. 11 at Croy Hill. Robertson's re-opening of this section revealed an earlier stone base at about 0.3 m below the exposed main stone base and projecting *c.* 0.6 m beyond the northern face of the Wall. This lower

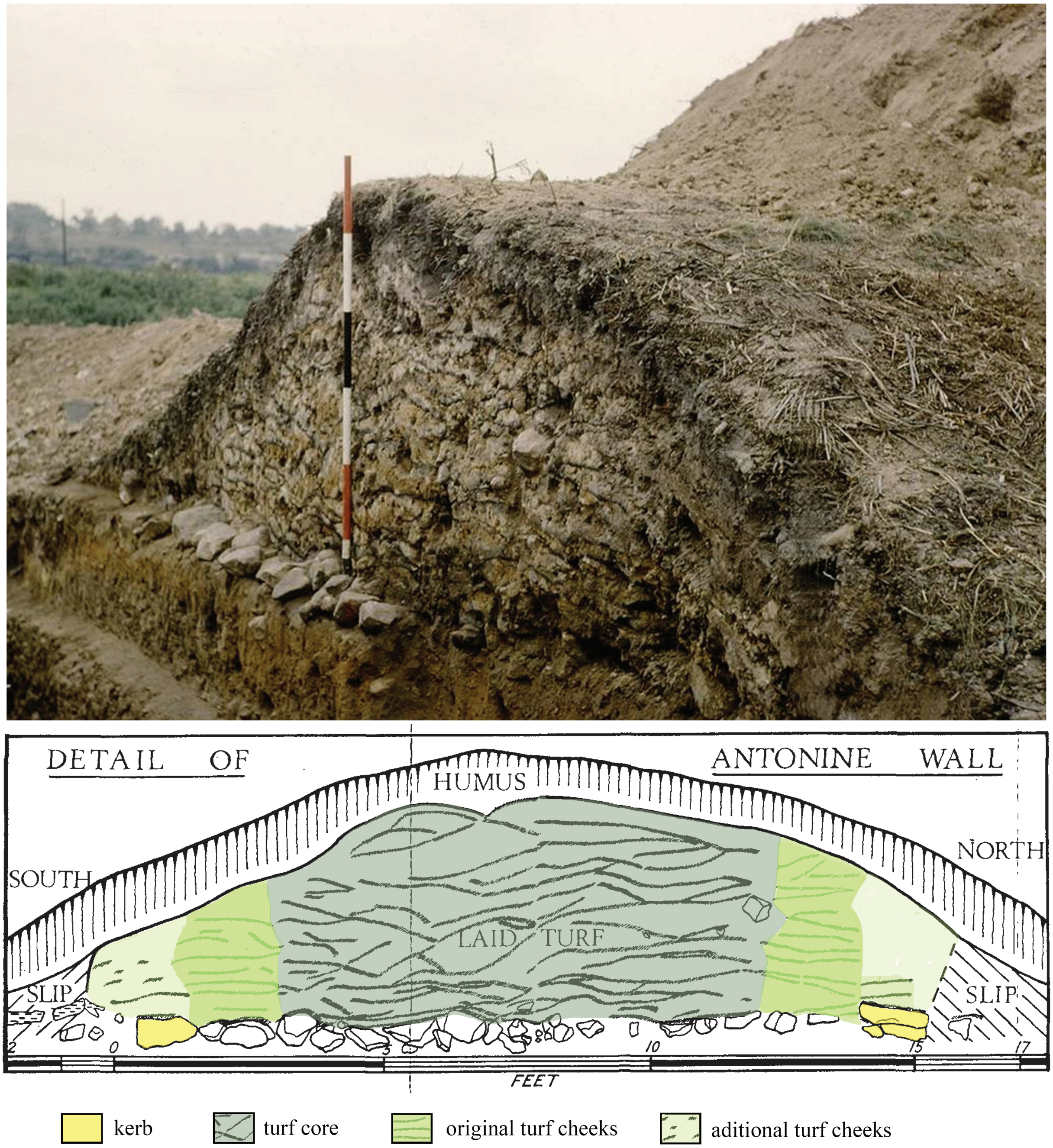

Figure 10.7. Section through Antonine Wall at Tentfield, central part, sector 3 (photograph and drawing). Turf core (grey-green) flanked by original turf faces to north and south (mid-green), these were contained by kerbstones (yellow). An additional turf face was added to north and south, on top of kerbstones, with potentially some later slumping to south (Photograph by A. Robertson, ©Crown copyright Historic Environment Scotland; drawn by T. Romankiewicz after Robertson 1964: Fig 5).

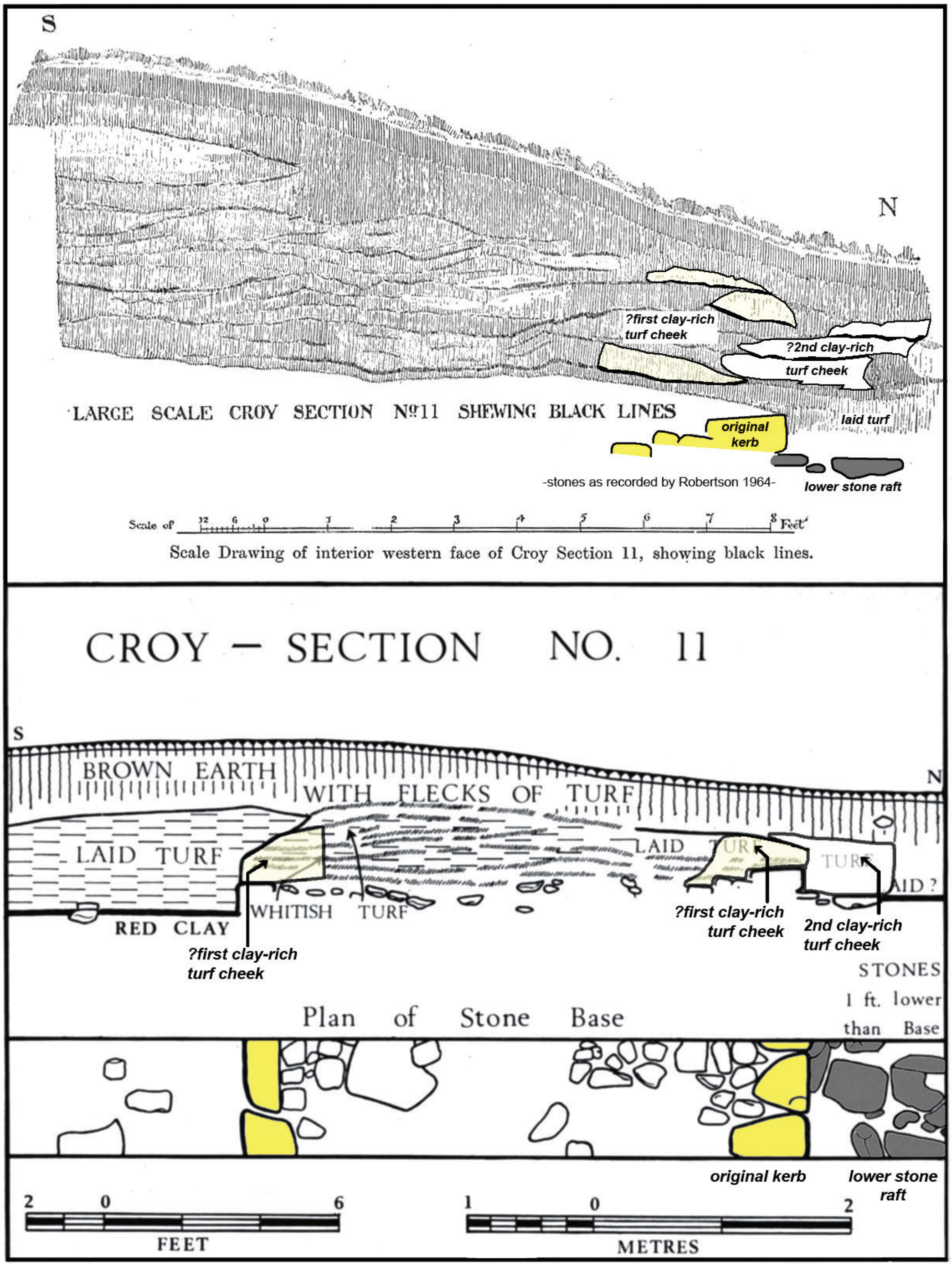

Figure 10.8. Sections and plan through Antonine Wall at Croy No. 11, central part, sector 5/6. 1890's section by GAS above, section and plan by A. Robertson 1967 below. Whitish clay blocks of northern and southern faces emphasized. Two narrow turf cheeks in north face interpreted as original cheek (yellow) coinciding with original kerb position, later cheek (white) built on top of added lower stone raft against slumping of earlier cheeks. Reopening of 1890s section by Robertson in 1967 showed laid turf in front of northern stone kerb, placed on stone raft *c.* 0.3 m foot than original base (drawn by T. Romankiewicz after GAS 1899: 73 and Robertson 1969: Fig 1).

stone base had ‘laid turf’ surviving on top (Figure 10.8) (Robertson 1969: 39). Instead of being earlier, could this raft have been wedged under the front edge of the existing kerb at a lower level to stop the kerb from subsiding (Figure 10.8, raft in grey)? Could the laid turf beyond the original kerb represent a later buttress against the original bulging north face as proposed for St Flannan’s Church above and at Tentfield (Figure 10.7)? If so, the original clay-rich turf cheek at Croy No. 11, *c.* 0.6 m wide, had been built either flush with the outer kerbstone, or was bounded by it, as the lowest course sits inwards from the kerb’s outer face, similar to the observations made at Tentfield (Figure 10.7). When this original cheek at Croy No. 11 started to slump, a new stone base was inserted at a lower level, propping up the original kerbstones and providing support for a secondary cheek, again built of clay-rich white turves. These were keyed into the failing original face to buttress it.

Evidence for the widening of the stone base to add new cheeks as part of more wholesale repairs has also been recorded at Balmuildy Road, where a line of cobbles had been placed in front of the eastern wall face of a stone base as narrow as 3.96 m. This may represent a later repair, or, as Keppie speculated, a widening of the base assessed as too narrow by the squad who were to construct the superstructure (1976: 67). At Hag Knowe, the expanded stone base was definitely a repair, because it rested on ‘tumbled turfwork’, and the excavator records a ‘drastic rebuilding’ due to either ‘destruction or at least collapse’ (see MacIvor in Keppie and Breeze 1981: 231). For the evidence at Bantaskin, Keppie argued that the repair on the northern side, resulting in a widening of the Wall base by about 0.5 m, was due to sagging of the superstructure, made of an orange clayey core ‘with some turf blocks thrown in’. This was faced on the north by ‘greyish lumpy’ clay, which he interprets as a turf cheek, and another turf cheek on the south identified by the red-brown lines of turf vegetation layers (Keppie 1976: 71-72). He sees the failing as related to water management problems exaggerated by the presence of a culvert in this area (Keppie 1976: 69). The dressed kerbstones of the new projection were carefully tied back into the existing kerb, not dissimilar to the interpretation made for Croy No. 11 above; again, this repair added the benefits of an underlying stone base for the new cheeks. The Bantaskin repair blocked the original culvert, and a few of its capstones were seemingly reused in the final resetting of the northern kerb. Similar evidence that repairs sometimes compromised the drainage function of the stone base were also seen at Wilderness West (Hanson and Maxwell 1983b: 232) or indeed in the obscured kerbstones described for Callendar Park above (Figure 10.6), as well as at Inveravon (Dunwell and Ralston 1995: 531, 535).

There is also good evidence for repairs to, and multiple phases of, clay cheeks. At Inveravon, in the area of the possible expansion to the Wall and the small fort, clay cheeks were used for all these structures, seemingly built at different phases, despite evidence for their failure (Dunwell and Ralston 1995: 532, 535 and 545). For the Wall, two cheeks about 0.3-0.4 m in thickness originally flanked an earthen core (Dunwell and Ralston 1995: 526). The southern cheek, which had a surviving width up to 0.3 m, was composed of a series of interleaved turf blocks, clay blocks and bands of yellow clay (Figure 10.3). In front of this, a thick deposit of 0.45 m depth extended southwards for about 7.5 m from the Wall cheek. The excavators interpret this as an ‘episode of collapse, with the clay cheek shearing off from the earthen core’ of the expansion structure(s), which was then covered by ‘a quantity of destabilized core material’ possibly also from the expansion (Dunwell and Ralston 1995: 530-531). Whether this collapse was due to structural failure or because of purposeful downtakings (‘deliberate slighting’) could not be established in the field. However, from a geotechnical engineering perspective, such a pattern of collapse is not surprising. The multiple layers and interleaving of the original cheeks, under wet conditions, could have made the Wall vulnerable to shearing. Bailey’s trench in Callendar Park is another key piece of evidence for the different uses and repairs of clay cheeks, and the repeated remodelling of the Wall faces (Figure 10.6) (1995: 580). His trench happened upon a total construction break. In the eastern half, the facings ('A') are described as 'blue' clay and have a width of 0.30 m. In the western half, the facings ('B') were made of 'white clay' up to 0.7 m wide; both are associated with different core material. The eastern core comprised orange silty-clay loam, grey clay loam, and a concentration of turves towards its centre, while the western core fill was made up of both orange and grey clay loam mixed together ('M'). Bailey used this evidence to argue that the stretch of Wall exposed in the western side of his trench was a complete repair in which not only the cheeks but the entire core had to be replaced (1995: 588).[3] The stratigraphic relationships between the different core materials suggests that 'B' and 'M' were the later repairs, in which case the mixed later core could be interpreted as containing recycled material from the disassembled earlier superstructure. Evidence for a time lapse between these two construction phases has been found in a 0.2 m high build-up of clay material in front of the northern kerb, which had eroded off the earlier clay cheek 'A' (Figure 10.6, in blue). This residue was later sealed by laid turves, which obscured the kerb; it was also sealed by the northern clay cheek 'B' and by the eventual collapse of these cheeks (Bailey 1995: 587). The 0.7 m wide cheeks labelled 'B' were keyed into the north face of 'A' and into its core, evidenced by the wedge-shaped spreads of 'B' into the core recorded in plan (Figure 10.6). This keying and the greater depth of the clay cheeks labelled 'B' could represent improvements on structural stability to counteract the tendencies of the clay cheeks to shear off from the core (compare Bailey 1995: 588).

New approaches to an old wall

The Antonine Wall, in terms of its materials and construction techniques, was not a unified monument; it varied considerably along its length. Likewise, this was a structure that was continually patched up, altered and in some cases seemingly substantially rebuilt. There is a danger, therefore, of assuming that all the variations identifiable in the structure of the Wall were part of the first phase of construction and can be credited to the original builders at the time – what we now see is a patchwork of multiple phases of intervention, most of which cannot be dated, and some of which are likely to have been undertaken by units different from the original building squads.

In what has been outlined above, three key points emerge:

1. The stone base appears to have been intended to help manage drainage across the line of the Wall and also moisture within the earthen superstructure; without it the structure may well have been unstable; this is a lesson that might well have been learnt elsewhere, such as on the western sector of Hadrian's Wall. The stone base, however, did not act as a load-spreading foundation.
2. Along the length of the Wall, the builders adapted the materials they used and the techniques employed. In those sections of the Wall with clay and turf cheeks, these features may well have assisted in the management of moisture within the structure and protected its core from erosion. However, clay cheeks would have been vulnerable to collapse unless they were keyed into the core and had some form of covering, which is not easy to reconstruct.

[3] For details of this and the full interpretation, see Bailey's original report (1995); this analysis concentrates only on the materials and construction of the superstructure. A wider assessment of the site will be published elsewhere.

3. The various sections of the Wall would have to have been regularly maintained and replaced. They would also have deteriorated at different rates. The repairs listed above show that this was a continually evolving monument.

These observations have significant implications for our understanding of the planning of the Antonine Wall, its appearance, and even its function. Such further discussion, however, lies well beyond the scope of the present paper and would benefit from more research, and more scientific analyses of the surviving materials.

The material presented here comprises the first steps of a larger project to analyse the construction of the Antonine Wall against the broader background of earth and turf building in the Roman north-western provinces more generally. This wider project will combine geotechnical with geoarchaeological analyses to include methods such as soil micromorphological analysis to examine the details of the soil properties, microscopic traces of now-decomposed vegetation horizons in the turves, and the *chaîne opératoire* of earth building (e.g. Cammas 2018). This research also aims to test the wider structural performance of the different materials and to reconstruct potential environmental settings where the turf blocks might have been sourced (compare Kunyong and Frederick 2017).

What the analysis so far has confirmed matches Graafstal's conclusion for Hadrian's Wall, that we should rethink these monuments not as vast and inherently logically progressing building projects, but as segmented and prioritised (Graafstal 2012: 148-149) – and reactive to both localised changes in landscape, as well as processes of decay and maintenance. Keppie's conclusion in 1974 certainly remains true: 'The building of the Antonine Wall ... was no simple process' (1974: 163). The glimpses offered by the small trenches excavated so far all seem to have complicated rather than simplified the long-standing questions about the building of the Antonine Wall. No doubt, the more complicated the evidence and in turn our conclusions, the closer to the real circumstances our explanations will be.

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